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Additive Manufacturing & composite – A review

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Abstract

Across the world, engineering has the common language and common goal- "improving the Quality of Life" of mankind without any boundary restrictions. A general review of the literature sources across different Additive Manufacturing process and performance in different orientations has shown that the publications are few in numbers. Aim of this paper is to provide general information of Additive Manufacturing process across different Prototyping systems. They can be used as a preliminary guide to help users to determine optimal Strategies for Rapid Prototyping system selection. The term "Rapid Prototyping"(RP) refers to class of technologies that can automatically construct physical models from computer aided design (CAD) data or is a group of techniques used to quickly fabricate a scale model of a physical part or assembly using 3-D CAD data to create tangible prototype of their design .Such models have numerous uses. They make visual aids for communicating ideas with co-workers or customers apart from design testing. The need of the hour is to bring together globally this fraternity to collaborate with each other.

Keyword: additive manufacturing, Rapid prototyping, composite materials.

INTRODUCTION

The technology is the process of composite and additive manufacturing; composites are defined as materials in which two or more constituents are brought together, producing a new material consisting of at least two distinct components, with resultant properties significantly different from those of the individual constituents. The process uses polymers and fiber reinforced composite materials. Each carbon filament thread is a bundle of many thousands of carbon filaments .The composites serves are predominantly aerospace, including commercial and military planes, helicopters, UMV Drones, and space vehicles, modern racing cars, oil drilling, Sporting goods etc. Laser Projection system assists in the process of hand lay up of piles more efficient a ply is a thin layer of composite materials with the additive manufacturing process.

RAPID PROTOTYPING

Rapid Prototyping (RP) is a term most commonly used to describe a variety of processes, which are aimed at quickly creating three-dimensional physical parts from virtual 3D computer models using automated machines. The parts are "built" directly from the 3D CAD model and can match that model very closely (within the precision limits of the chosen process). Rapid prototyping is different from traditional fabrication in that it is only possible through the use of computers, both to generate the 3D CAD model data, as well as to control the mechanical systems of the machines that build the parts. Virtually all RP processes are "additive". Parts are built up by adding, depositing, or solidifying one or more materials in a horizontal layer-wise process. The part is built up layer by layer until done. This is similar to the result one would get if one made a topographical map of the object, with the contour lines representing the layer thickness of the process..In addition to additive production processes, one must also consider the possibilities of subtractive processes such as CNC machining and laser cutting. Subtractive processes, as the name implies, create objects by removing unwanted material from a large block or sheet in the form of chips. CNC machining of 3D CAD models (normally called CAD/CAM) is not actually considered a rapid prototyping process (although it can be as fast), but both additive and subtractive approaches are important aspects of today's prototyping industry. RP technologies are able to create one-piece part geometries which would be difficult if not impossible to create by machining, including overhangs, undercuts and enclosed spaces. To create these types of structures RP technologies often rely on a support material, which is used alongside the model material. These automatically generated supports must be removed after the part is finished. Other processes rely on the unused model material to support the part being built. However, machining is still able to produce finer surfaces, more accurate and larger parts in a much wider variety of materials than RP processes are currently able to, and complex models may often be built up out of assemblies of simpler, easier to machine parts. Thus, the two types of technologies, additive and subtractive, continue to co-exist and be complimentary in the 3D prototyping world. The materials which are available for RP use will depend on the process chosen and are still relatively limited, but the variety is growing. There are a number of plastics and resins commonly used, as well as some process that can use things like starch, plaster, wax and metal. The word "Rapid" in RP is a relative term, as most of these processes are actually quite slow. The rapid actually refers to the reduced time from initial design to the production of the final part. This is due to the elimination of extensive amounts of hand and machine work involved in making prototypes with traditional methods, as well as the ability to quickly iterate and test a design through various stages. Also, as contrasted with more complicated CAM programming and CNC machining .RP software and machines are generally simple and quick to use, resulting in significantly reduced "human time" needed to produced prototype parts .RP processes are generally quiet ,non-dangerous processes which can run in an office environment 24/7.This contrast with machining, which generally needs a workshop or factory environment (noise, dust, liquids) and has a number of safety issues. RP is an Automatic Process for manufacturing parts, prototypes, tools and even assemblies directly from their CAD models without the use of any cutters ,tools or fixtures, specific of the object and without any human intervention anywhere in the process. A RP machine is a CNC machine with an embedded CAPP system for additive manufacturing .RP is also a "divide and conquer" manufacturing strategy in which a complex 3D manufacturing problem is converted onto several 2Dmanufacturing problems which could be automated. The following are the benefits of RP.

- Rapid prototypes act as concept models for better visualization and communication.
- Marketing personnel can use to assess the artistic appeal of the product by displaying in showrooms.
- RP can be used for form, fit and functional test.
- Transparent rapid prototypes obtained from photo-polymers are using photo-elasticity.
- RP can be used for wind tunnel tests.
- Assemblies can be made without joints using RP methods.
- RP can be sent along with the inquiries; RP models can be submitted along with the quotations.
- There are important medical applications in conjunction with Reverse Engineering.
- RP cuts down product ionizing time and hence sharpens the competitive edge of the organization.
- RP emerging into Rapid Manufacturing is possible in some applications.
- With an integrated approach RP & T can shorten time to market.

Although RP & T could make the prototypes only out of proprietary non-metallic materials and the accuracy and surface finish are not adequate, direct and indirect methods are emerging to overcome these limitations. Hybrid technologies which exploited the best features of CNC and RP are also emerging. These efforts will shortly enable making objects rapidly from their CAD models automatically out of the required material with the specified quality.

RAPID PROTOTYPING PROCESS

3D CAD models can be made with many, many different software packages (and sometimes can pass through several), each will have its own way of representing surfaces and volumes. The problem for the user is to be able to prepare this model for 3D printing or Rapid prototyping. In general, what is needed is one or more completely closed volumes. The RP software may be able to understand and automatically correct small openings and errors, but large holes or open objects will result in not being able to print (without the file being first repaired).Since different programs work in different ways and have different file formats, it will be necessary to "translate" the representation of the model in that software into something more "universal" that the RP software can understand. This translation process (like any translation) can introduce problems into the process that were not apparent in the original. In general, from the 3D CAD software, we need to export the model as a STL file. Nearly all 3D programs can export an STL and most can import them.

STL FILE

An STL is a type of standardized computer exchange file which contains a 3D model. The representation of the surface(s) of the object(s) in the file is in the form of one or more polygon meshes. The polygon meshes in an STL file are entirely composed of triangular faces, edges and vertices. Further, the faces have assigned normal which indicate their orientation (inside/outside). The name "STL" is taken from its extension, .stl, originally because the files were intended for the rapid prototyping process called Stereo lithography. The file format has become a world standard for exchanging 3D polygon mesh type objects between programs, and .stl's are now used as input for virtually all rapid prototyping processes, as well as some 3D machining.

1. Stereolithography

Stereo lithography is the most widely used rapid prototyping technology. Stereo lithography builds plastic parts or objects one layer at a time by tracing a laser beam on the surface of a vat of liquid photopolymer, inside of which is a movable stage to support the part being built. The photopolymer quickly solidifies wherever the laser beam strikes the surface of the liquid. Once one layer is completely traced, the stage is lowered a small distance into the vat and a second layer is traced directly on top of the first. The self-adhesive property of the material causes each succeeding layer to bond to the previous one and thus form a complete, three-dimensional object out of many layers.

Objects which have overhangs or undercuts must be supported during the fabrication process by support structures. These are either manually or automatically designed with a computer program specifically developed for rapid prototyping. Upon completion of the fabrication process, the object is removed from the vat and the supports are cut or broken off.

Stereo lithography generally is considered to provide the greatest accuracy and best surface finish of any rapid prototyping technology. Over the years, a wide range of materials with properties mimicking those of several engineering thermoplastics have been developed. Limited selectively color changing materials for biomedical and other applications are available, and ceramic materials are currently being developed. The technology is also notable for the relatively large size range of objects possible, from parts as big as a car wheel to as small as a sugar cube, with excellent accuracy relative to the scale of the object.On the negative side, the photopolymers are expensive and perishable, working with liquid materials can be messy and parts require a post-curing operation in a separate oven-like apparatus for complete cure and stability.

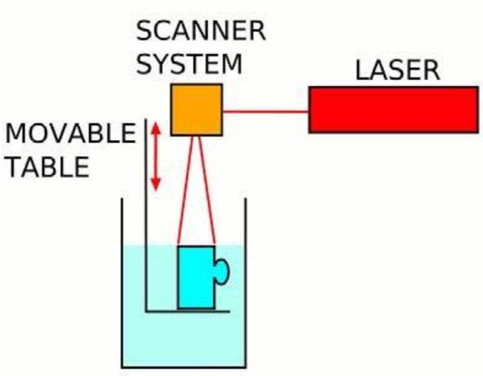

Fig-1

Materials: Principally photo curing polymers which simulate polypropylene, ABS, PBT, rubber; development of ceramic-metal alloys

Getting the .STL correctly into the RP machine software

Since an STL mesh is composed entirely of triangles, it is the simplest form of mesh model format. Each facet is necessarily planar. In principle, for rapid prototyping processes, a completely closed object is required, that is to say, the mesh completely encloses a volume, with no holes, gaps, or overlaps. We sometimes speak of this as a “watertight solid”. In addition, the software controlling some processes requires that there is only one object (volume) in the file.

In actual practice, there may be some tolerance allowed. Small errors or gaps may be tolerated by the prototyping software, or can be quickly repaired. Some software may allow multiple and overlapping objects. Each process and software will work differently; some are more error-tolerant than others. Therefore, in general it is best to aim to achieve a perfect 100% closed model, otherwise, depending on who is doing the prototyping and what process is being used, it may be time consuming (read: expensive) to fix.

Professional service bureaus and frequent users of RP parts will have specific software designed to manipulate and fix .stl models and prepare them for prototyping. One example of this might be Magic's by Materialize (B). This type of software is expensive, but has specific tools for analyzing the integrity of .stl models and rapidly correcting defects (often automatically). They may also have other functions that permit the model to be cut into smaller parts, shelled, nested, etc. Once the .stl is 100% correct and verified, it can then be imported into the machine-specific RP software which will generate the commands to run the machine. This data is then sent to the machine (like a printer) and the model construction is started.

2. PolyJet (photopolymer phase change Inkjet)

PolyJet is an industrial 3D printing process that builds multi-material prototypes with flexible features and complex parts with intricate geometries in as fast as 1 day. A range of hardnesses (durometers) are available, which work well for components with elastomeric features like gaskets, seals, and housings.

Working of polyjet:-The PolyJet process begins by spraying small droplets of liquid photopolymers in layers that are instantly UV cured. Voxels (three-dimensional pixels) are strategically placed during the build, which allow for the combination of both flexible and rigid photopolymers know as digital materials. Each voxel has a vertical thickness equal to the layer thickness of 30 microns. The fine layers of digital materials accumulate on the build platform to create accurate 3D-printed parts.

Each PolyJet part is completely coated in support material during the build, which ultimately is removed by hand using a pressurized water stream and a chemical solution bath. No post-curing is required after the manufacturing process. The process is based on photopolymers, but uses a wide area inkjet head to layer wise deposit both build and support materials. It subsequently completely cures each layer after it is deposited with a UV flood lamp mounted on the print head. The support material, which is also a photopolymer, is removed by washing it away with pressurized water in a secondary operation. Resolution of Objet printers essentially equals that of standard stereolithography systems, and development is ongoing. Several materials are available, including transparent, flexible and black. The advantage of polyjet systems over SLA systems is that the resins come in cartridge form (no vat of liquid photopolymer), the machines are clean, quiet and office friendly. There is less post processing cleanup on parts. Disadvantages are that the print heads are relatively expensive and need to be replaced regularly, adding to maintenance costs.

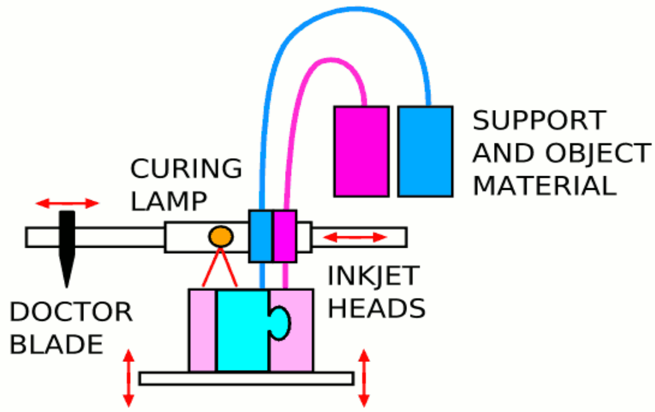

Fig-2

Materials: Photopolymer resin

3. Three dimensional Printing(3DP)

It's often used as a direct manufacturing process as well as for rapid prototyping.The process starts by depositing a layer of powder object material at the top of a fabrication chamber. To accomplish this, a measured quantity of powder is first dispensed from a similar supply chamber by moving a piston upward incrementally. A roller or scraper then distributes and compresses the powder at the top of the fabrication chamber. The multi-channel jetting head subsequently deposits a liquid adhesive (binder) in a two dimensional pattern onto the layer of the powder (similar to inkjet printing). The binder bonds the powder particles together where it has been deposited, solidifying it to form a layer of the object.

Once a layer is completed, the fabrication piston moves down by one layer thickness, and the process is repeated until the entire object is formed within the powder bed. After completion, the object must be removed from the chamber still filled with powder (a delicate operation), and the excess powder brushed off, leaving a "green" object. No external supports are required during fabrication since the powder bed supports overhangs. Three dimensional printing offers the advantages of speedy fabrication and low materials and system cost. In fact, it's probably the fastest of all RP methods. It is even possible to print colored parts and images onto the part surfaces. However, there are limitations on resolution, surface finish, part fragility and available materials. In order to face the problem of the fragility of the standard 3DP plaster and starch parts, the object can be “infiltrated” with a resin, which hardens the object once it cures, but even then the break resistance does not equal that of some other systems such as FDM. 3D printing is also being used with sand and a high temperature resin to create sand casting molds and cores for metal casting, as well as acrylic for creating plastic prototype parts (voxeljet).

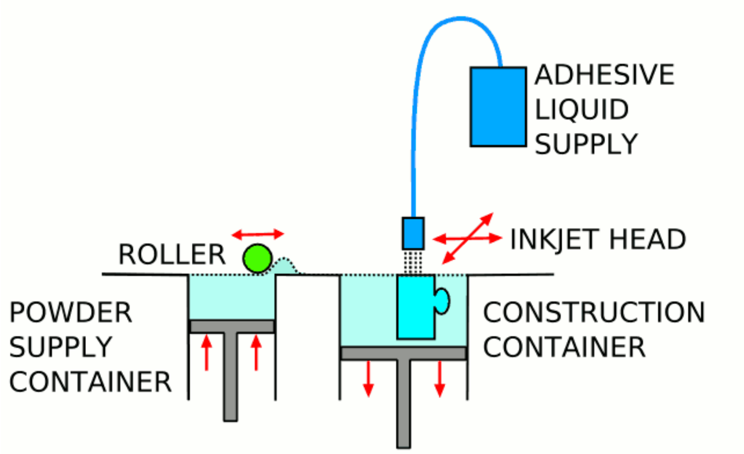

Fig-3

Model materials: plaster, sand, corn starch, acrylic

Binder and infiltration materials: various resins, cyanoacrylates (infiltrating)

4. Fused Deposition Modeling (FDM)

FDM is the second most widely used rapid prototyping technology, after stereolithography. A plastic filament is unwound from a coil and supplies material to an extrusion nozzle. The nozzle is heated to melt the plastic and has a mechanism which allows the flow of the melted plastic to be turned on and off. The nozzle is mounted to an X-Y plotter type mechanism which traces out the part contours, There is a second extrusion nozzle for the support material (different from the model material). As the nozzle is moved over the table in the required geometry, it deposits a thin bead of extruded plastic to form each layer. The plastic hardens immediately after being squirted from the nozzle and bonds to the layer below. The object is built on a mechanical stage which moves vertically downward layer by layer as the part is formed. The entire system is contained within a chamber which is held at a temperature just below the melting point of the plastic. Several materials are available for the process including ABS and investment casting wax. ABS offers good strength, while the polycarbonate (PC) and polyphenylsulfone (PPS) materials offer more strength and a higher temperature range.

Support structures are automatically generated for overhanging geometries and are later removed by breaking them away from the object. A "water-soluble" support material is also available for ABS parts. The method is office-friendly and quiet. FDM is fairly fast for small parts on the order of a few cubic centimeters. It can be very slow for large parts with a lot of volume, however. Depending on the part geometry and orientation, it can also require more support material than the part itself (or virtually none). The finished parts are anisotropic, that is they exhibit different mechanical characteristics in different directions. The resolution is not as fine as with stereolithography, but the parts are more robust.

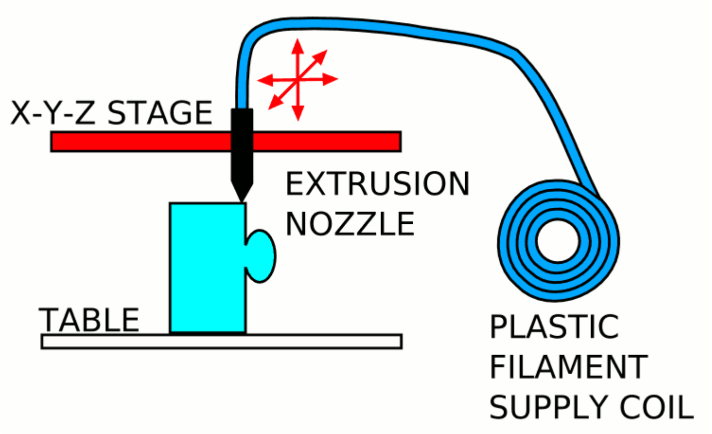

Fig-4

Materials: ABS, ABSi, PC, PC-ABS and PC-ISO, PPS (model material)

5. Selective Laser Sintering (SLS)

Thermoplastic powder is spread by a roller over the surface of a build cylinder. The piston in the cylinder moves down one object layer thickness to accommodate the new layer of powder. A piston moves upward incrementally to supply a measured quantity of powder for each layer.A laser beam is traced over the surface of this tightly compacted powder to selectively melt and weld the grains together to form a layer of the object. The fabrication chamber is maintained at a temperature just below the melting point of the powder so that the laser elevates the temperature slightly to cause sintering - the grains are not entirely melted, just their outer surfaces - which greatly speeds up the process. The process is repeated, layer by layer, until the entire object is formed.

After the object is fully formed, the piston is raised. Excess powder is simply brushed away and final manual finishing may be carried out. No supports are required with this method since overhangs and undercuts are supported by the solid powder bed. It takes a considerable cool-down time before the part can be removed from the machine. Large parts with thin sections may require as much as two days of cooling.SLS offers the key advantage of making large sized functional parts in essentially final materials. However, the system is mechanically more complex than stereolithography and most other technologies. A variety of thermoplastic materials such as nylon, glass filled nylon, and polystyrene are available. Surface finishes and accuracy are not as good as with stereolithography, but material properties can be quite close to those of the intrinsic materials. The method has also been extended to provide direct fabrication of metal and ceramic objects and tools.

Since the objects are sintered they are porous. It may be necessary to infiltrate the part, especially metals, with another material to improve mechanical characteristics

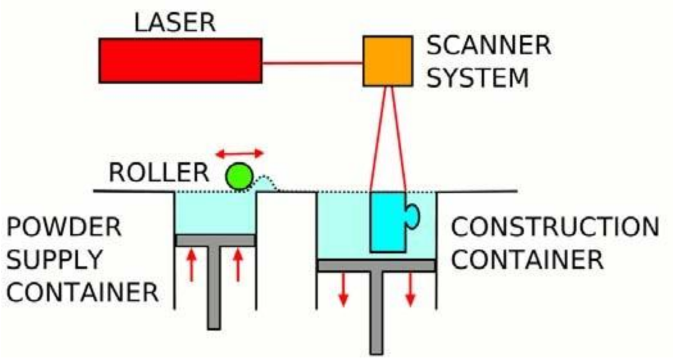

Fig-5

Materials: Plastics **-** polystyrene, nylon, glass filled nylon, alumide (aluminum/nylon blend), **Materials:** Metals **-** aluminum, stainless steel, titanium, gold (virtually any metal can be sintered)

6. Laminated Object Manufacturing (LOM)

Profiles of object cross sections are cut from paper or other web material using a laser. The paper is unwound from a feed roll onto the stack and first bonded to the previous layer using a heated roller which melts a plastic coating on the bottom side of the paper. The profiles are then traced by an optics system that is mounted to an X-Y stage. After cutting of each layer is complete, excess paper is cut away to separate the layer from the web. Waste paper is wound on a take-up roll. The method is self-supporting for overhangs and undercuts. Areas of cross sections which are to be removed in the final object are heavily cross-hatched with the laser to facilitate removal. It can be time consuming to remove extra material for some part geometries, and there is a lot of inherent waste in the process, as every object uses up an amount of material equivalent to a box that contains the part - even if the part itself is very thin walled. Variations on this method use a knife to cut each layer instead of a laser or apply adhesive to bond layers using the xerographic process. There are also variations which seek to increase speed and/or material versatility by cutting the edges of thick layers diagonally to avoid stair stepping.

In general, the finish, accuracy and dimensional stability of paper objects are not as good as for materials used with other RP methods. In addition, the laser cutting of the material creates a lot of smoke and needs to be ventilated to the outside. However, material costs are very low, and objects have the look and feel of wood and can be worked and finished in the same manner. This has fostered applications such as patterns for sand castings. While there are limitations on materials, work has been done with plastics, composites, ceramics and metals. Low cost machine which uses PVC film (more controllable and stable than paper). These are addressing market segments ranging from concept modeling to very large objects for architectural applications.

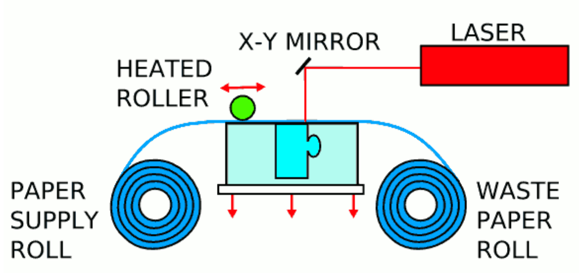

Fig-6

Materials: Typically paper rolls but recently also plastic films

7. **Prometal:** Prometal is 3D printing process to build injection tools and dies. This is Powder based process in which stainless steel is used. The printing process occurs when a liquid binder is spurt out in jets to steel powder. The powder is located in a powder bed that is controlled by build pistons that lowers the bed when each layer is finished and a feed piston that supply the material for each layer. After finishing, the residual powder must be removed. When building a mold no postprecessing is required. If a functional part is being built. Sintering, infiltration, and finishing processes are required. In the sintering process the par is heated to 177^{0}C for 24 hour hardening the binder fusing with the steel in a 60% porous specimen. In the infiltration process the piece is infused with bronze powder they are heated together to more than 1100^{0}C. The same process, but with different sintering temperatures and times has been used with other materials like a tungsten carbide powder sintered with zirconium copper alloy for the manufacturing of rocket nozzles, these parts have better properties than CNC machine parts of the same material.

8. **Laser Engineering Net Shaping:** In this additive manufacturing process a part is built by melting powder that is injected into a specific location. It becomes molten with the use of a high powered laser beam. The material solidifies when it cooled down. The process occurs in a closed chamber with an argon atmosphere. This process permits the use of a high variety of metals and combination of them

like stainless steel, nickel-based alloys, titanium-6, aliminium-4,vanadium, tooling steel ,copper alloys ,and so forth. Alumina can be used too. This process is also used to repair parts by other processes will be impossible or more expensive to do. One problem in this process could be the residual stresses by uneven heating and cooling processes that can be significant in high precision process like turbine blades.

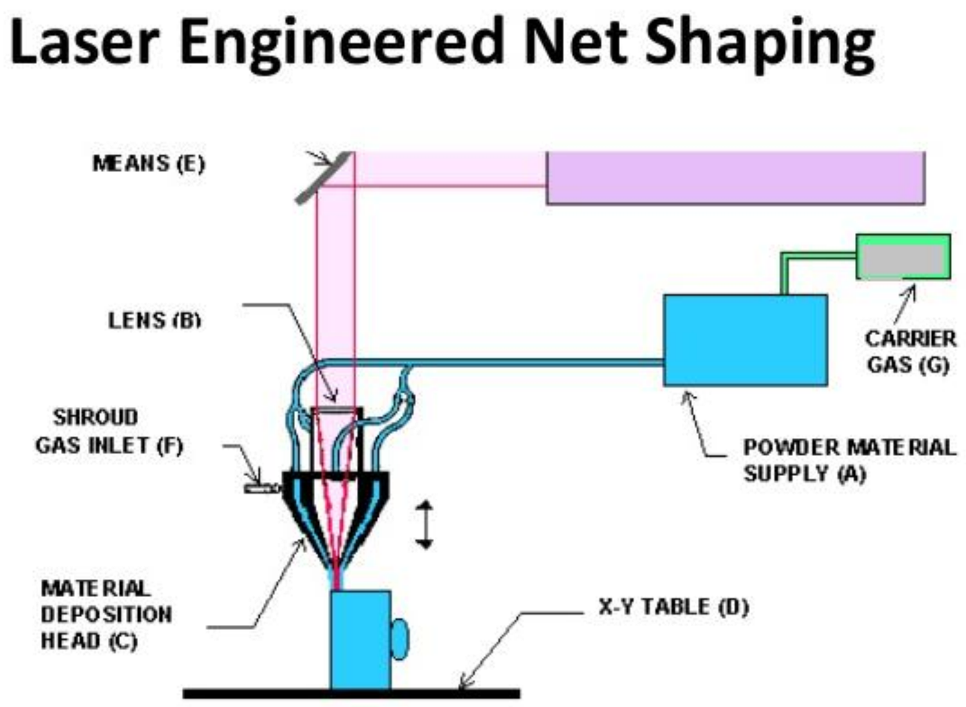

Fig-7

9. **Electron Beam Melting (EBM) :** A process similar to SLS is electron beam melting . This process is relatively new but is growing rapidly. In this process, what melts the powder is an electron laser beam powered by a high voltage, typically 30 to 60 KV . The process takes place in a high vacuum chamber to avoid oxidation issues because it is intended for building metal parts .Other than this ,the process is very similar to SLS.EBM also can process a high variety of pre alloyed metals. One of the future uses of this process is the manufacturing in outer space, since it is all done in a high vacuum chamber.

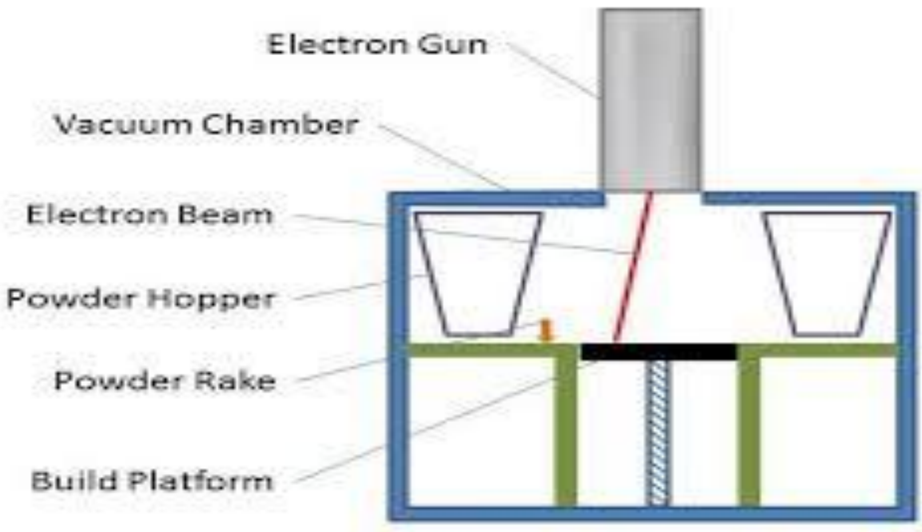

Fig-8

FUTURE DEVELOPMENT

To revolutionize manufacturing, one such improvement is increased speed.”Rapid” Prototyping machines are still slow by some standards. By using fastest computers, more complex control systems and improved materials, RP manufacturer are dramatically reducing time to make economical for a wider variety of products. Another future development is improved accuracy and surface finish. Toda’s available machines are accurate to 0.08 millimeters in X-Y plane, but less in the Z (vertical) direction. The introduction of non-polymeric materials, including metals, ceramics and composites, represents another much anticipated development. These materials would allow RP users to produce functional parts. Research labs are working to develop new materials, investigating ways to make ceramics using fused deposition modeling .Another development is increased size capacity, concrete models up to 3.3m x 2m x1.2m in size. The product size is limited only by the size of the robot holding the laser .All the above improvements will help the Rapid prototyping industry continue to grow, both worldwide and at home.

SUMMARY

This paper provides an overview of RP technology in brief and emphasizes on their ability to shorten the product design and development process. Classification of RP process and details of few important processes is given. Finally the rise of rapid prototyping has progress in traditional methods as well. Modern CNC machining centers can have spindle speeds upto 100000 RPM, with correspondingly fast feed rate. Rapid prototyping will not make machining obsolete, but rather complement it.

CONCLUSION

Additive Manufacturing is poised to transform the production of "Physical goods" in much the same way that the internet transformed the production of "informational goods". Many people recognize these opportunities and are starting new businesses, designing future products and funding research focused around Additive Manufacturing capabilities.

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